

forward E.M.F. to overcome it. The reduction in the electronic emission involves the potential difference between the poles in another way, because it diminishes the ionisation, and therefore increases the resistance of the vapour of the arc. For this reason the back E.M.F. at the anode is not quite the same as the difference between columns 2 and 3, namely, 7·5 volts.

A Collision Predictor.

By J. JOLY, Sc.D., F.R.S.

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In a recent paper in these Proceedings* I described a method by means of which the mariner is enabled to foretell risk of collision at sea, assuming that he knows the course and speed of each of the vessels concerned and that he is at intervals able to ascertain the distance separating them. For an account of the principles involved I must refer to my former paper. A simple geometrical construction enabling them to be applied is therein given. This construction informs the navigator whether there is risk of collision or not, and also enables him to ascertain the instant at which the danger is greatest.

However simple in character, it is probable that, to the average seaman, the operations involved in a geometrical construction would appear less practical than a mechanical or instrumental mode of interpreting the observations. It will be an additional attraction to an instrumental method if time be saved by its use. For the time available for the solution of the problem involved may be short. This might well be the case if the earlier signals for any reason escaped notice. Accordingly I have endeavoured to reduce the work of interpreting the observations to the simplest form. Of various types of apparatus for the interpretation of the geometrical principles involved, that which I now describe is, I believe, the easiest both to work and to construct.

The instrument consists (see fig. 1) of the half disc, *d*, which is graduated to compass divisions (and to degrees if desired); the points being named both for easterly and westerly bearings. Rotating stiffly around the centre of the circle, on a joint which admits of being clamped, two graduated limbs, *a* and *b*, are fixed. These limbs are mutually inclinable on a friction joint similar to that used on an ordinary folding rule. The limb *b* carries a sliding piece,

* P. 176, *supra*.

e, which supports the arm *c*. This arm rotates round a centre located upon that edge of *b* which passes through the centre of rotation of *a* and *b*. It is

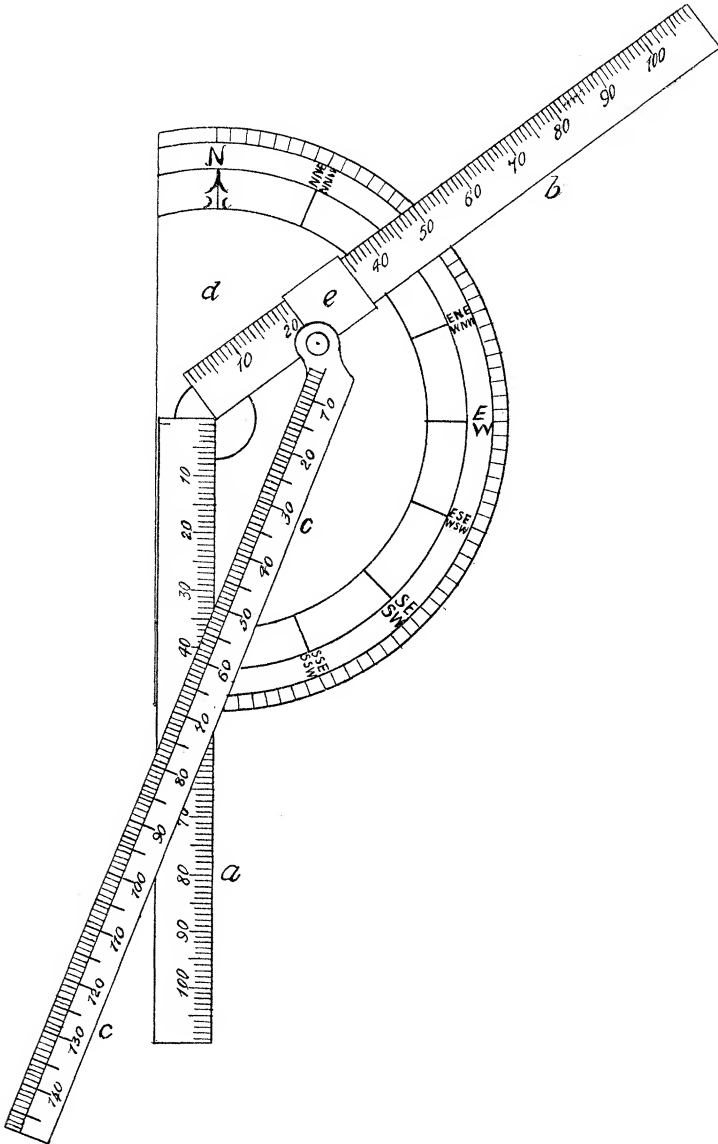


FIG. 1.

also on one edge of the sliding piece. It can be securely clamped in any position. All three bars are graduated to any convenient scale of subdivisions. Millimetres would be suitable. These are given to natural scale

in the figure, but it would, in general, be advisable to construct the instrument to larger dimensions than those shown.

The Collision Predictor is used in the following manner. When the first signals are received by a ship (which we will call A) from another ship (which we will call B) the navigator on A places the limbs a and b to the courses of the two vessels and clamps them in those positions: the limb b being set to the course of the vessel B and the limb a to the course of A. Thus, in the figure, B is holding a course N.E. $\frac{3}{4}$ E. and A is holding a course due south.

The navigator next slips the slider e along the limb b till it reads on the scale of b a number of millimetres representing the displacement of B in the interval between the signals. We will assume that this interval is two minutes. He also sets the arm c to read, on the limb a , a number of millimetres along the limb representing the displacement of his own ship A, during the same interval, and to the same scale. This is most easily done by reading on the scales one scale division (*i.e.* one millimetre) per knot per hour. Thus, if B is doing 11 knots the slider is advanced to 11 on the limb b , and if A is doing $16\frac{1}{2}$ knots the arm c is brought to intersect the limb a at $16\frac{1}{2}$ scale divisions on a . Taking one millimetre to represent one knot this is the same as multiplying the distances done in two minutes by 30.*

The distance separating the vessels as given by the first signal is now laid off—still to the same scale—along the arm c . Suppose it was 4 knots. The navigator lets 120 ($= 4 \times 30$) upon c represent this distance. A sliding marker on the arm c may be provided, if desired, to mark the number representing the first distance. These operations are in preparation for the second signal.

When the second signal arrives, giving him the new value of the distance separating the vessels, the navigator considers how many divisions on c it represents according to the scale already chosen. Thus if the new distance is 3.2 knots this corresponds to 96 ($= 3.2 \times 30$) divisions of the scale c . And now the first crucial reading is obtained. For if the intercept on c by the limb a is 24 divisions (or very nearly this) collision is threatened. If it is a different number there is no danger. It will be noticed that $24 + 96 = 120$; which is the reading on the scale c representing the original distance.

In order to confirm this observation the navigator now sets forward the slider e in readiness for a third signal. He need not interfere with the arm c , for this moves along with e , keeping parallel to its first position. It will, therefore, automatically take up the right position on a corresponding to the shift of e . In the figure I suppose the slider e brought into the position for

* In the figure double these readings are shown because the Collision Predictor is supposed to be set for the third signal, as will presently appear.

the third signal. It reads 22, *i.e.* it has been advanced another 11 mm. The reading on *a* is also twice the first reading. The navigator notices that this movement makes the intercept on the scale *c* closely 50 divisions. If, then, the first reading is to be confirmed the ensuing distance signal will correspond to 70 divisions (or nearly this) on the scale; for $70 + 50 = 120$, which is the reading for the original distance. When it comes at the end of two minutes the distance is found to be 2.3 knots. Now $2.3 \times 30 = 69$. Hence the first indication of threatened collision is confirmed.

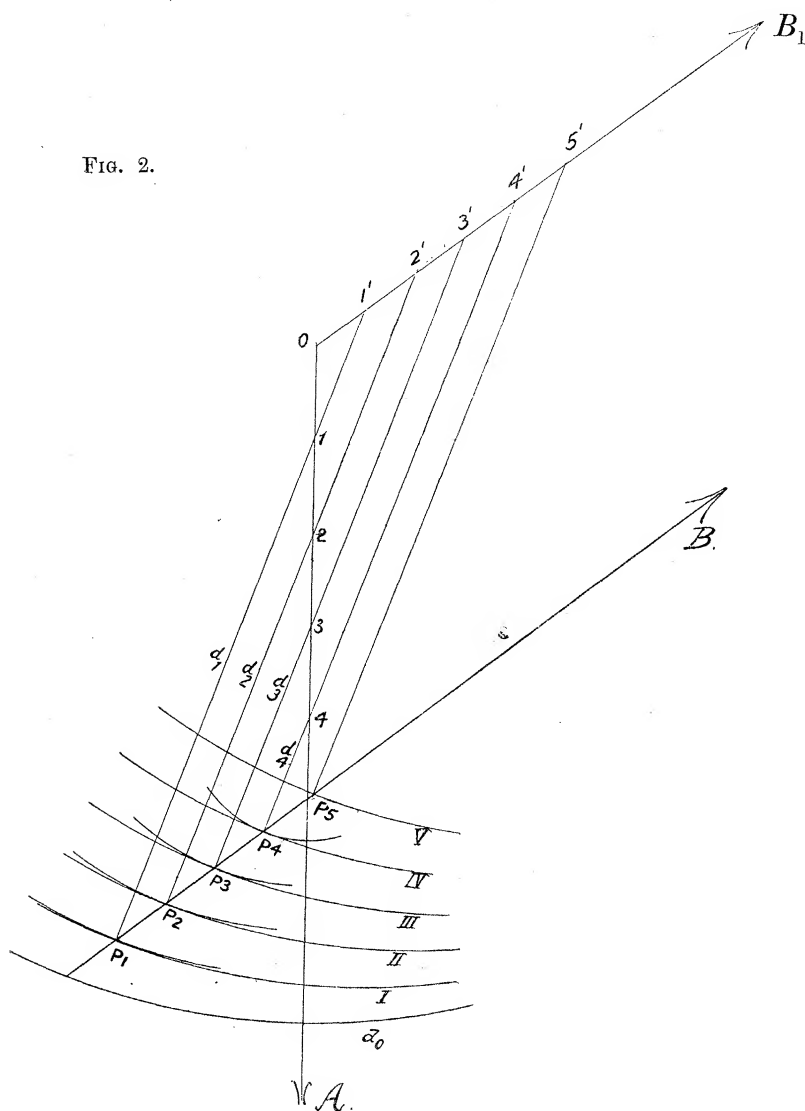
This observation may be further confirmed by the fourth signal according as time permits. The approach of the two vessels to one another may in this way be kept under observation. But it is well, so soon as danger is certainly indicated, to ascertain the moment when the danger is greatest and collision may actually occur if precautions are not taken. The moment of collision is ascertained as follows.

When the distance separating the ships is reduced to nothing is the moment of collision. Now the distance is 0 when the intercept by *a* on the arm *c* is 120 divisions. But at the rate of shifting the slider *e*, three more shifts will bring the division 120 (on *c*) a little past the edge of *a*. But three shifts represent six minutes since the receipt of the third signal, assuming two minutes as the interval between the signals. Collision may thus be regarded as imminent at a time $5\frac{1}{2}$ minutes from the receipt of the third signal. It will be seen that the navigator has, here, ascertained the moment of threatened collision by moving the slider along the limb *b* till the division on *c* representing the original distance reaches the edge of *a*, and reckoning two minutes for every 11 divisions by which the slider is displaced on the limb *b*.

It will be gathered from what has now been stated that the operations involved—arithmetical and mechanical—are of the simplest kind. Under the circumstances which may often attend the use of the instrument, it is important that they should be of a character which are not likely to be confused, and which can be rapidly performed. A very little practice will suffice to place the navigator in complete command of the operations involved. These amount, essentially, to observing whether the distances determined by the successive signals are equal to the balance of the original distance left upon the scale of *c* after the intercept between the limbs *a* and *b* is deducted. Between each signal the mariner has, therefore, only to shift forward the slider by the assigned amount—conveniently, a number of millimetres equal to the knots per hour done by the ship B. He then reads the balance of distance left upon the scale of *c*, *i.e.*, between its point of contact with *a* and the scale number representing the original distance. That is to say, he makes one shift of *e* and takes one reading on *c*.

He is then ready for the next signal. These operations are easily effected in less than half a minute of time. He has ample time to consider his position, or, it may be, to attend to another vessel. But for the latter contingency a duplicate Collision Predictor should be at hand.

The theory of this instrument is simple enough. In fig. 2, from the point 0 we lay off the course of B as a line OB_1 bearing N.E. $\frac{3}{4}$ E. and the course of the ship A as a line bearing due south. With 0 as centre and the first



distance d_0 as radius, the circle d_0 is described. If we assume A to be at O, B is situated somewhere upon this circle.

Keeping the radius d_0 , we now go to the points $1'$, $2'$, $3'$, etc., which are spaced to represent the displacement of B on her course every two minutes (or whatever other interval separates the signals), and describe the circles I, II, III, etc. We know that B, in succeeding intervals of two minutes, is transferred from one of these circles to the next.

Along the course of A from O, we lay off the points 1, 2, 3, etc., spaced to represent the displacement of A along her course every two minutes. In these representations of distance we preserve the same scale throughout. Now, when A has got to 1, the second signal is received, giving the distance separating the ships as d_1 . If, therefore, we describe a circle about 1 with d_1 as radius, we know that B at this instant is situated on this circle. But she is also upon circle I struck from $1'$. We know, then, that she is located at either of the two points of intersection of the circles, but we cannot tell which. Now, this is the case for safety from collision, as explained in my former paper (*loc. cit.*).

But in the particular case when collision is threatened, the two circles touch at a point of tangency (as in fig. 2). At this point B must be placed. Similarly, if we repeat this construction, going to the point 2 with the distance d_2 , we get a point of tangency on the circle II. We may do this for each new position of A and B. The line joining these points of tangency must be the path of B approaching A. It necessarily keeps a N.E. $\frac{3}{4}$ E. course, and is therefore parallel with the line through O representing the course of B. We might, evidently, have found the line of advance of B from a single point of tangency by drawing through this point a line having the N.E. $\frac{3}{4}$ E. direction. The tangent points are lettered p_1 , p_2 , etc., in the figure.

This construction, I may recall, is based upon the fact that if collision is to occur, the rate of approach of B to A must be the greatest possible for the courses and speeds of the two ships. The distances $1p_1$, $2p_2$, etc., are evidently the least distances connecting the points of position 1, 2, etc., with the arcs of position I, II, etc., and it follows the rate of approach of B to A is greatest along the line p_1p_5 .

Now, the tangency of two circular arcs involves the point of contact being upon the line connecting the centres of the circles. Hence, when collision is threatened, the lines $1p_1$, $2p_2$, etc., which are equal to d_1 , d_2 , etc., must be in direction with the lines $1'1$, $2'2$, etc., and as the line p_1p_5 is necessarily parallel with the line OB' (both being directed in the course of B), and the lines $1'p_1$, $2'p_2$, etc., are mutually parallel owing to the similarity of the

triangles $1'01$, $2'02$, etc., the distances $1'p_1$, $2'p_2$, etc., are equal to one another and to the original distance d_0 .

From this simple geometry the use of the Collision Predictor is evidently justified. For the distance of B from A at any instant, as read along the arm c , is, in fact, the distance marked d_1 , d_2 , etc., in the figure, and the amount of the intercept of the limb a on the arm c is the length $1'1$, $2'2$, etc. The fact that when their summation equals the value of d_0 collision is threatened amounts to the same statement as that there is tangency of the successive circles of position, and hence greatest rate of mutual approach of the vessels.

The confidence we place in the use of this instrument must depend on the sensitiveness with which it interprets the observations. With sharply engraved divisions and suitable dimensions, the Collision Predictor will be found to read as closely as the errors incidental to the observations render desirable. That is to say, in the case of a threatened collision, a small departure from the rate of maximum approach is unmistakably revealed. Fig. 3 will serve to contrast the nature of the readings obtained in the case of threatened collision and of safety.

The vessels A and B are directed on the courses shown. That is, B is heading N.W. and A is heading W.N.W.* B is going the faster, so that she is overtaking A.

Now, for collision, we have the condition shown by the full-drawn arcs giving the tangent points p_1 , p_2 , etc., of the unique line marked B, for the path of the ship B. Collision will occur when this line meets the line A.

For conditions of safety the arcs with broken lines are drawn. These give two possible paths for B, each marked β .

Now the arc d_0 is, of course, common to both conditions. But if it is to be safety the values of d_1 , d_2 , etc. will be greater than the corresponding values in the case of collision. Thus $d_1 = 1\pi_1$, the radius of the first dotted arc, is greater than $1p_1$, the radius of the first tangent arc, by the bit $p_1\pi_1$. Similarly $2p_2$ (collision) is exceeded by $p_2\pi_2$, when there is safety. And, again, $3p_3$ is exceeded by $p_3\pi_3$. And these excesses are evidently sufficient to reveal the different conditions of safety and danger. Thus the mariner obtains assurance of safety or intimation of danger at an early stage in his observations.

The limits of observational errors must always be borne in mind, but the errors will not accumulate. They will involve a certain latitude in each determination of distance. We may assume this latitude or uncertainty to be approximately known in amount. But each observation is independent of

* These bearings are set over eastward as they would lie upon the Collision Predictor.

its predecessor as a determination of distance. Hence when we see an increasing value for the excess $p\pi$ in successive readings on the arm c , we are justified in concluding that the condition of maximum rate of approach is really departed from and there is no danger of collision. In fig. 3, $p_1\pi_1$ might be—we may suppose—an excess based on error. But we see that $p_2\pi_2$ is considerably greater than $p_1\pi_1$. The value $p_3\pi_3$ is still greater and altogether beyond the limits of error in reading the distance from the signals.

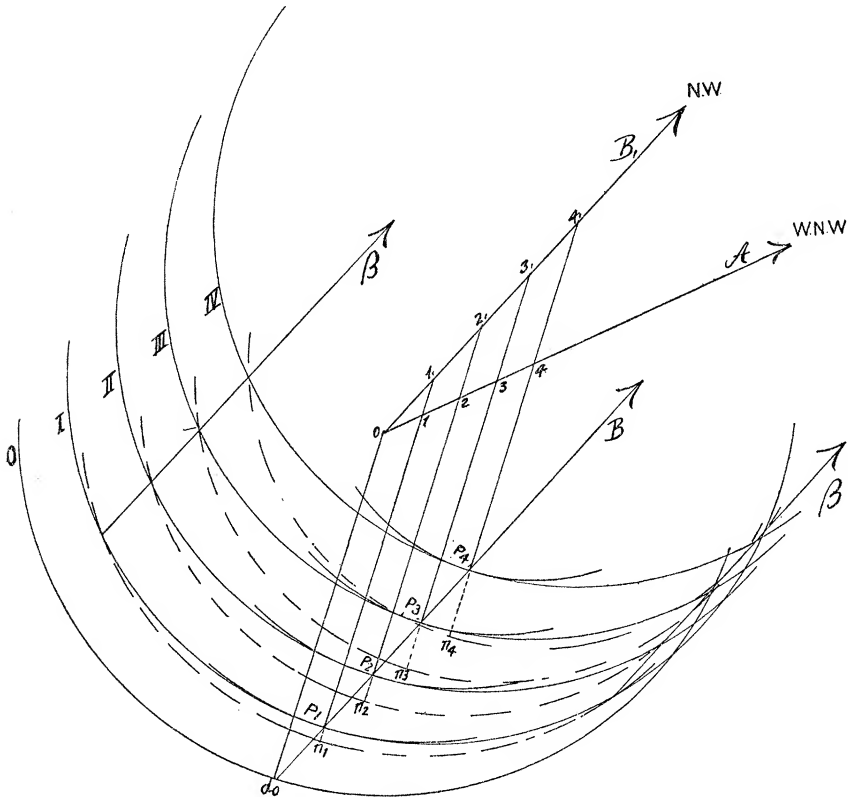


FIG. 3.

The Collision Predictor tells the navigator whether collision is threatened or not, and it also tells him when it is threatened. It does not give him the two alternative paths of the other ship when she passes wide of his own vessel. This, however, is information which the sailor does not, generally, require.

When A and B are holding the same or a directly opposite course, the Collision Predictor cannot be profitably applied. But the question of collision or safety is in these cases, as before, solved by simple addition or subtraction of figures. If the courses are opposite and if collision is threatened the

vessels must be in line and the rate of approach the maximum. Hence if A does m knots between the signals and B does n knots the rule holds that $d_0 = d_1 + (m + n) = d_2 + 2(m + n)$, etc. Again, if one vessel is overtaking the other, both being on the same course, the rate of approach is a maximum if collision is threatened and $d_0 = d_1 + (m - n) = d_2 + 2(m - n)$, etc., when A is overtaking B. If this arithmetical relation is not found to hold for the successive determinations of distance, and if the amount of departure from equality increases with each observation, there is safety. The vessels are not proceeding in the same line.

On the Oxy-hydrogen Flame Spectrum of Iron.

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A few lines in the visual region of the oxy-hydrogen flame spectrum of iron were recorded in 1887 by Sir Norman Lockyer.* This list was supplemented in 1893† by a map showing all the then known flame lines of iron in the photographic region. In the following year Hartley‡ published his researches on "Flame Spectra at High Temperature," including a list of lines in the spectrum obtained by heating compounds of iron in the oxy-hydrogen flame. This list extends from λ 5927.7 to λ 3021.1.

Flame spectra of iron have been studied in great detail by de Wetteville, working alone or in collaboration with Hemsalech. In particular they have published§ an extensive list of wave-lengths and intensities of lines observed in the oxy-hydrogen flame fed by a current of oxygen previously passed through a globe in which an electric spark was being maintained between iron poles.

It may also be mentioned that reproductions of photographs of the iron flame spectra have been published in the atlases of Hagenbach and Konen (1905) and Eder and Valenta (1911).

Some preliminary results obtained from a spectrum of iron burning in the

* 'Roy. Soc. Proc.' vol. 43, p. 120 (1887).

† 'Phil. Trans.,' A, vol. 184, pp. 675-726, Plate 28 (1893).

‡ 'Phil. Trans.,' A, vol. 185, pp. 199-202 (1894).

§ 'Comptes Rendus,' vol. 146, p. 964 (1908).